Powder Technology 333 (2018) 404–409

Contents lists available at ScienceDirect

Powder Technology

journal homepage: www.elsevier.com/locate/powtec

Effect of particle properties on the energy-size reduction of coal in the ball-and-race mill

Weining Xie [a,*], Yaqun He [a,b,**], Lili Qu [b], Xiaolu Sun [b], Xiangnan Zhu [c]

[a] Advanced Analysis & Computation Center, China University of Mining & Technology, Xuzhou, Jiangsu 221116, China
[b] School of Chemical Engineering and Technology, China University of Mining & Technology, Xuzhou, Jiangsu 221116, China
[c] School of Chemical & Environmental Engineering, Shandong University of Science & Technology, Qingdao, Shandong 266590, China

ARTICLE INFO

Article history:
Received 6 December 2017
Received in revised form 10 March 2018
Accepted 12 April 2018
Available online 23 April 2018

Keywords:
Narrow size-ash coal
Energy-size reduction model
Breakage behavior
Response of energy consumption

ABSTRACT

Breakage behaviors and energy consumed characteristics of coal are directly influenced by properties, such as particle size, ash content or density. It is essential to model these effects and conduct quantitative evaluation. In this study, samples of 4 particle sizes × 4 ash contents were ground in a Hardgrove mill for 9 energy levels, respectively. Breakage rate of particles in the top size and t_{10} were determined and effects of coal properties on two parameters were also discussed. Though the relation between consumed energies and t_{10} of each sample can be described by classical breakage model, experimental data of all samples were scatter. In this case, particle size and ash content were modelled into breakage equation in exponential term, namely $t_{10} = A \times (1 - e^{-b \cdot x \cdot E_{cs}/eY_a})$. This modified model gave good fitting results to experimental data. Introduce of coal properties into energy-size reduction model helps to compare grinding energy efficiency of various coals. Confidence analyses of repeat experiments demonstrated the repeatability of test results and indicated the reliability of new breakage model.

1. Introduction

Particle breakage is an energy-intensive process. Improvement of grinding efficiency and reducing energy consumption should base on a good understanding of energy-size reduction process. Though coal power plants make great contributions to electrical energy, nearly 0.5–2% of electric power generation is consumed by pulverizing system [1]. But, attention paid to this problem is not enough. Aiming to the effective combustion of pulverized fuel (PF) in furnace, raw coal should be ground for several times to meet PF standard of $R_{90} < 15\%$ and $R_{200} < 5\%$ (R_{90} means the yield of +90 μm particle in PF) [2]. Associated minerals would be ground for more times to reach this fineness due to large hardness. Also, energy consumption of mineral grinding is huge compared with that of pure coal. In China, the fuel policy stipulates that power plants should use low quality coal for electric power generation. In this case, ash content of raw coal and energy consumption are higher than those of power plants in developed countries, where high quality coal of less minerals are used.

Vertical roller mill (VRM) is widely used in coal power plants to prepare PF, and flow direction of coal in VRM is shown in Fig. 1. Particle breakage and classification happens in closed phenomenon. First, coal particles on grinding table are broken under the loading force of roller. Then, coal fines leave rotatable grinding table and flow to elutriator by hot primary air for the first rough classification. Some coarse particles return to table for regrinding, but mass flow is relatively small. Fine products of elutriator enter classifier for the second classification, where the classification efficiency is much higher than that of elutriator due to the centrifugal force. Fine particles are PF and coarse rejects are to be ground with the new feed of VSM [3]. Fig.1 also indicates that grinding mechanism of VSM is similar to that of Hardgrove mill. So researchers used Hardgrove machine to conduct simulation studies of particle breakage in VSM [4–6]. Some scholars also designed lab-scale mills with tire-shaped rollers instead of balls [7,8]. Particle breakage process in VSM was studied and described by batch grinding model [9] and energy-size reduction model [10], respectively. Except for experimental studies, industrial sampling tests were also conducted for E and MPS type VSMs (which used balls and rollers as grinding media, respectively) by The University of Queensland and China University of Mining and Technology [11,12]. Multi-component models, including sub-models of particle breakage and classification, were established to study effect of primary air flowrates on VSM operation [1,13]. Sub-model of particle breakage was developed from the JK classical one [14]. Namely,

$$t_{10} = A \cdot \left(1 - e^{-b \cdot E_{cs}}\right) \quad (1)$$

* Corresponding author.
** Correspondence to: Y. He, School of Chemical Engineering and Technology, China University of Mining & Technology, Xuzhou, Jiangsu 221116, China.
E-mail addresses: aacc_xwn5718@cumt.edu.cn, (W. Xie), yqhe@cumt.edu.cn. (Y. He).

https://doi.org/10.1016/j.powtec.2018.04.018
0032-5910/

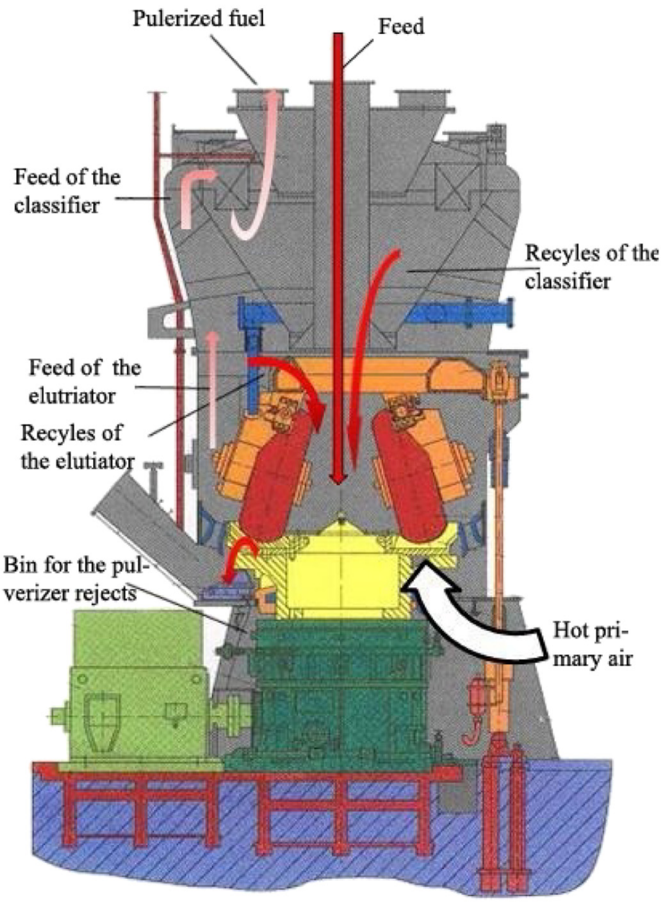

Fig. 1. Flow direction of coal in VSM [3].

where t_{10} is the amount of progenies in size of less than the 1/10th of feed mean size (%), E_{cs} is the mass specific energy ($kWh \cdot t^{-1}$), A and b are ore impact breakage parameters.

Later, a multi-component breakage model was established, with the addition of particle size and density based on size-by-density grinding tests [15,16]. This equation showed the following form:

$$t_{10} = \frac{M}{(RD/RD_{min})^c} \cdot \{1 - exp[-f_{mat} \cdot x \cdot E]\} \quad (2)$$

where t_{10} has been defined in Eq. (1), M represents the maximum t_{10} for a material subject to breakage (%), RD is the relative density of particle, RD_{min} is the minimum relative density of sample ($RD_{min} = 1.25$ for coal), f_{mat} is the material breakage property ($kg \cdot J^{-1} \cdot m^{-1}$), x is the initial particle size (m), E shows the same meaning to E_{cs} in Eq. (1).

These breakage models related t_{10} to consumed specific energy, and could reveal effect of particle size and density on energy-size reduction of coal. Besides these models, batch breakage models were also used [17–20], which showed a good predicted result for grinding tests in short time [21]. Selection and breakage distribution functions in matrix form were two important parts of this model. Though this model was used for several decades, there were some problems. First, solution of batch grinding model was difficult as selection and breakage distribution functions changed with time. Second, for continuous grinding tests, results predicted by batch model may not be accurate, as residence time of particles on grinding table was not discussed. Third, batch model was proper for coarse grinding, and predicted results for fine grinding were not well. Fourth, energy consumption was not considered in batch grinding model. In this case, the JK classical model, which links input (specific energy) and output (t_{10}) of particle breakage, is referenced and modified in this paper. Effect of particle properties on the energy-size reduction process is discussed based on the modified model.

For a certain grinding device, breakage behavior of samples is influenced by particle properties. Usually, samples in narrow size or density fraction are used to precisely study effects of particle properties on breakage behavior. In this paper, grinding tests are conducted for coals with various size fractions and ash contents in a Hardgrove mill. Based on size distribution analyses of ground progenies, breakage rates of particles in initial size and t_{10} are determined and compared. Initial size and ash content are introduced into energy-size reduction equation, and this modified model is used to analyze change of specific energy and t_{10} to coal properties.

Table 1
Ash contents of coal samples in narrow size and density fraction.

Size/mm	Ash content/%			
2.8–2	5.40	15.78	24.02	61.42
2–1.4	5.45	18.04	31.68	57.98
1.4–1	6.10	15.66	24.39	65.84
1–0.71	5.94	16.87	25.23	68.41

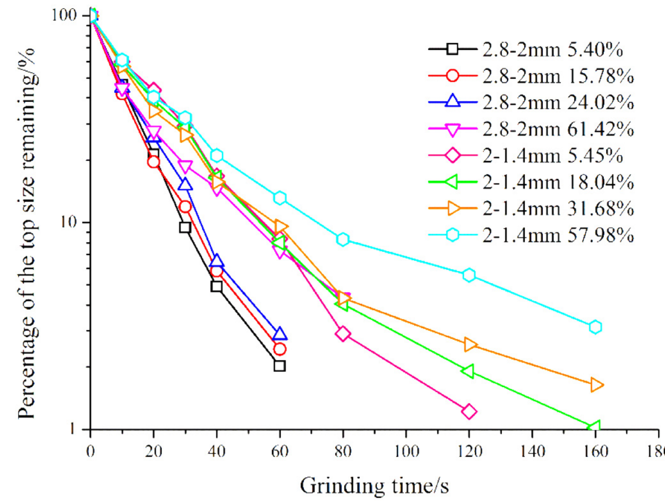

Fig. 2. Relation between percentage of the top size remaining and grinding time for 2.8–2 mm and 2–1.4 mm coal particles.

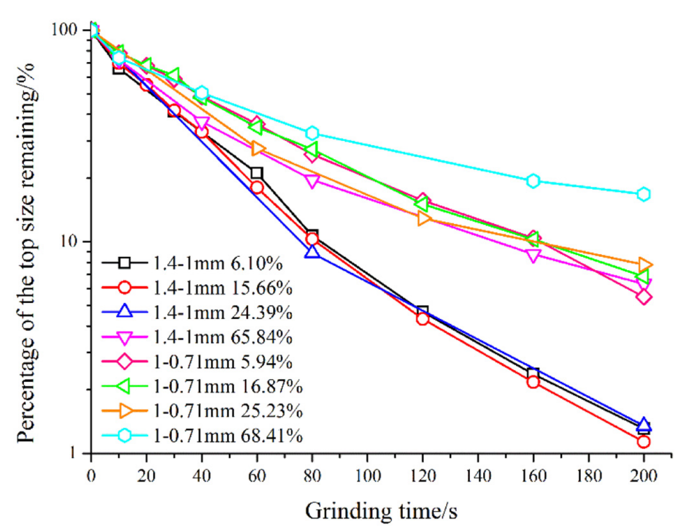

Fig. 3. Relation between percentage of the top size remaining and grinding time for 1.4–1 mm and 1–0.71 mm coal particles.